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Replacing monensin and virginiamycin with essential oils and short-chain fatty acids in feedlot beef cattle fed a whole shelled corn-based diet: performance, dry matter intake, and ruminal fermentation

Substituição da monensina e da virginiamicina por óleos essenciais e ácidos graxos de cadeia curta em bovinos de corte confinados com dieta de puro grão: desempenho, consumo de matéria seca e parâmetros ruminais

Reemplazo de monensina y virginiamicina por aceites esenciales y ácidos grasos de cadena corta en ganado vacuno confinado a una dieta pura de granos: rendimiento, consumo de materia seca y parámetros ruminales

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Abstract
The objective of this work was evaluating the replacement of monensin and virginiamycin with essential oils and short-chain fatty acids on performance, dry matter intake, and ruminal fermentation in beef cattle fed a whole shelled corn-based diet. A total of 36 young bulls initially averaging 6 ± 2 months old and 257.2 ± 17.2 kg body weight (BW) were allotted to two treatments: 1) diet containing virginiamycin and monensin and 2) diet containing essential oils and short-chain fatty acids. The animals were adapted to the whole shelled corn-based diets by receiving 85% whole corn grain and 15% proteic-mineral pellet for 14 days. The experimental period was of 98 days. Performance, dry matter intake (% BW), feed-to-gain ratio, fecal pH, ruminal pH, and volatile fatty acids in the rumen fluid were assessed. The study was conducted using a completely randomized design. A difference was observed in the average daily gain (P<0.01). No significant differences were found in dry matter intake (% BW) and feed-to-gain ratio (P>0.05). Regarding volatile fatty acids in ruminal fluid, differences (P<0.01) were observed only for acetic acid. Except for the 22:00 h, differences (P<0.01) in ruminal pH were observed in all sampling times (06:00, 14:00, and overall). Therefore, replacing monensin and virginiamycin with essential oils and short-chain fatty acids in beef cattle fed a whole shelled corn-based diet was effective for performance without impairing ruminal fermentation, which could affect animal health.
Keywords: Energy efficiency; Natural additives; Plant extracts; Sustainability.

Resumo
Objetivou-se com este trabalho avaliar a substituição da monensina e virginiamicina por óleos essenciais e ácidos graxos de cadeia curta sobre o desempenho, consumo de matéria seca e parâmetros ruminais em bovinos de corte alimentados com dietas de puro grão. Foram utilizados 36 bovinos machos inteiros com idade média de 6 ± 2 meses

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de idade com 257,2 ± 17,2 kg de peso vivo médio inicial divididos em 2 tratamentos sendo eles: dieta com virginiamicina e monensina e dieta com óleos essenciais e ácidos graxos de cadeia curta. Os animais foram adaptados às dietas de puro grão na proporção de 85% de milho grão inteiro e 15% de núcleo proteico mineral durante 14 dias e permaneceram 98 dias em período experimental. Foram realizadas avaliações de desempenho, consumo de matéria seca em % do peso vivo, conversão alimentar, pH das fezes, pH ruminal e quantidade de ácidos graxos voláteis no rúmen. O estudo foi realizado em um delineamento inteiramente casualizado. Foi observado diferença no ganho médio diário (P<0,01) no período experimental. Para as variáveis de consumo de matéria seca em % do peso vivo e conversão alimentar não foram encontradas diferenças significativas (P>0,05). Em relação a quantidade de ácidos graxos voláteis, só foram encontradas diferenças (P<0,01) para a produção de ácido acético. Com exceção do período das 22:00 horas, todos os períodos avaliados (06:00; 14:00 e geral) apresentaram diferença significativa (P<0,01) para pH ruminal. Concluiu-se que a substituição de monensina e virginiamicina por óleos essências e ácidos graxos de cadeia curta em bovinos de corte alimentados com dietas de puro grão mostrou-se efetiva para o desempenho sem prejuízo para os parâmetros ruminais, que pudesse a vir comprometer a saúde animal.
Palavras-chave: Aditivos naturais; Eficiência energética; Extratos vegetais; Sustentabilidade.

Resumen

El objetivo de este trabajo fue evaluar la sustitución de monensina y virginiamicina por aceites esenciales y ácidos grasos de cadena corta sobre el rendimiento, el consumo de materia seca y los parámetros ruminales en ganado vacuno alimentado con dietas puras de granos. Se utilizaron 36 bovinos machos enteros con una edad promedio de 6 ± 2 meses de edad y 257,2 ± 17,2 kg de peso vivo promedio inicial, divididos en 2 tratamientos: dieta con virginiamicina y monensina y dieta con aceites esenciales y ácidos grasos de cadena corta. Los animales fueron adaptados a dietas puras de cereales en una proporción de 85% de maíz integral y 15% de núcleo de proteína mineral durante 14 días y permanecieron en el periodo experimental durante 98 días. Se realizaron evaluaciones de rendimiento, consumo de materia seca en % de peso vivo, conversión alimenticia, pH fecal, pH ruminal y cantidad de ácidos grasos volátiles en el rumen. El estudio se llevó a cabo en un diseño completamente al azar. Se observó una diferencia en la ganancia diaria promedio (P<0,01) en el período experimental. Para las variables consumo de materia seca en % de peso vivo y conversión alimenticia no se encontraron diferencias significativas (P>0.05). En cuanto a la cantidad de ácidos grasos volátiles solo se encontraron diferencias (P<0.01) para la producción de ácido acético. Con excepción del período de las 22:00 horas, todos los períodos evaluados (06:00; 14:00 y general) mostraron una diferencia significativa (P<0.01) para el pH ruminal. Se concluyó que la sustitución de monensina y virginiamicina por aceites esenciales y ácidos grasos de cadena corta en ganado vacuno alimentado con dietas puras de granos demostró ser eficaz para el rendimiento sin comprometer los parámetros ruminales, lo que podría comprometer la salud del animal**.**
Palabras clave: Aditivos naturales; Eficiencia energética; Extractos de plantas; Sostenibilidad.

1. Introduction

Brazil currently has the largest commercial cattle herd in the world with approximately 196.4 million head, which gives it the status of the second largest carcass equivalent (9.7 million tons) producer and the greater beef exporter (2.4 million tons in carcass equivalent) in the world (Abiec, 2022). However, Brazilian livestock has been constantly challenged by the need for technologies to make meat production more efficient and sustainable, mainly by reducing the slaughter age and greenhouse gas emissions per kilo of product produced.

Thus, various products classified as feed additives are available in the market and can be used to increase performance in both the growth and termination phases. In Brazil, ionophores (mainly monensin) and non-ionophore antibiotics (virginiamycin) are the main feed additives used to improve animal feed efficiency.

In addition to improving animal performance, feed additives have also been recommended when animals are fed a high amount of concentrate. Feed additives can reduce metabolic diseases, such as acidosis, by suppressing gram-positive bacteria, especially lactic acid-producing bacteria (*Streptococcus and Lactbobacilus spp*.) and maintaining a greater ruminal pH without compromising nutrient fermentation.

However, some countries from the European Union have banned these feed additives since 2006 based on their selective effects on rumen microorganisms that could also increase antimicrobial resistance in humans, causing an impact on public health (Ferro, et al., 2016).

Therefore, other compounds, such as essential oils or plant extracts, have been used in cattle nutrition to modulate ruminal fermentation. These essential oils possess active substances which have been reported to be efficient when fed alone or combined and, due to their different mechanisms of action, prevent bacterial resistance (Cutrim, et al., 2019).

Some essential oils have ionophore-like traits in selecting the ruminal microbial population. They change the fermentation pattern and reduce the acetate-to-propionate ratio in addition to contributing to reducing enteric methane emission, which promotes more ruminal energy efficiency (Calsamiglia, et al., 2007).

According to Hart et al. (2008), the main effect of essential oils on the rumen is related to the reduction of protein and starch degradation attributed to a selective effect on certain microorganisms. Essential oils act on the structure of the bacterial cell wall, causing protein denaturation and coagulation, which changes the permeability of the cytoplasmic membrane. This altered ion gradient leads to the deterioration of essential cellular processes, such as electron transport, protein translocation, phosphorylation, and other enzyme-dependent reactions, which results in the loss of cellular chemostatic control and bacteria death (Benchaar, et al., 2008).

Therefore, the objective of this work was evaluating the replacement of monensin and virginiamycin with essential oils in feedlot beef cattle fed whole shelled corn-based diets.

2. Methodology

The present study was conducted at the Experimental Farm of the Centro Multiplicador de Capacitação (CMC), located in Martinho Campos (Minas Gerais - Brasil), from November 2022 to March 2023.

A total of 36 *Bos taurus* × *Bos indicus* (½Holstein × ½ Gir) young bulls averaging 258.1 ± 38 kg of body weight and 6 ± 2 months old were used. Before the beginning of the experiment, the cattle were submitted to vaccination and deworming. Animals were adapted to the facilities and the experimental whole shelled corn-based diets for 14 days.

At the beginning of the adaptation period, animals were randomly distributed into one of two groups (Baby Beef® or Factor LM+®). Animals were individually housed in partially covered dirt floor pens (25 m²) equipped with drinking troughs and feeders. Diets were offered once a day (08:00h) for an *ad libitum* intake (5% leftovers, on an as-fed basis) using a forage wagon, and animals had free access to water throughout the experimental period, which lasted 98 days.

Animals were weighed using an electronic scale after a 12-hour fast (solid and liquid) at the beginning and end of the experiment. Weighings were also performed weekly to diet supply follow-up. The amount of diet supplied and leftovers were recorded daily to calculate dry matter intake (DMI). The experimental diets (Table 1) were formulated to meet the nutrient requirements of beef cattle, gaining 1.4 kg/animal/day (NRC, 2016).

Table 1 - Ingredients and chemical composition of the experimental diets.

	Diet (%, as-fed basis)	
Whole corn	85	85
Proteic-mineral pellet Baby Beef FT®	15	-
Proteic-mineral pellet Factor LM+®	-	15
Nutrient		
Dry matter (%) [1]	86.9	87.3
Crude protein (%) [2]	14.6	14.1
Non-fiber carbohydrates (%) [2]	56.7	56.7
Neutral detergent fiber (%) [2]	11.3	11.0
Ash (%) [2]	2.85	2.91
Ether Extract [2]	3.6	3.4
Total digestible nutrients (%) [2]	85.2	85.0
Starch (%) [2]	60.7	60.5
Gross energy (Mcal/kg) [2]	3651.0	3681.0

1 – As-fed basis; 2 – Dry matter basis. Source: Authors.

The chemical composition of the proteic-mineral pellets is showed on Table 2.

Table 2 - Chemical composition of experimental proteic-mineral pellet.

	Proteic-mineral pellet Baby Beef FT®	**Proteic-mineral pellet Factor LM+®**
Dry matter (%) [1]	89.07	90.11
Crude protein (%) [2]	41.7	40.1
Non-fiber carbohydrates (%) [2]	15.4	15.3
Neutral detergent fiber (%) [2]	15.7	15.9
Ash (%) [2]	14.3	15.3
Ether Extract [2]	2.1	2.5
Total digestible nutrients (%) [2]	68.0	68.1
Virginiamycin (ppm) [2]	150	-
Monensin (ppm) [2]	150	-
Gross energy (Mcal/kg) [2]	3568.0	3511.0

1 – As-fed basis; 2 – Dry matter basis. Proteic-mineral pellet: 150 mg/kg virginiamycin and 150 mg/kg monensin. Proteic-mineral pellet Factor LM+: a blend of essential oils and short-chain fatty acids. Source: Authors.

Feces samples (15 g) were collected directly from the rectum. Samples were immediately mixed with 100 ml of deionized and demineralized water and stirred to obtain a homogeneous mixture. Afterward, pH was measured using a calibrated Akso pH meter (Turgeon, 1983).

During the experimental period, ruminal fluid was sampled using an esophageal probe and a suction device, as previously described by Bouda et al. (1996). The ruminal fluid pH was measured immediately after sampling using an Akso pH meter calibrated with buffer solutions (pH = 4, 7, and 10). Ruminal fluid samples (125 g) were immediately frozen and sent to the laboratory (CBOLAB, Valinhos, São Paulo, Brazil).

Ruminal fluid samples were centrifuged at 15,000 *g* (4ºC) for 50 minutes before the short-chain fatty acids analysis. Samples were injected into a liquid-gas chromatograph (Hewlett-Packard 5890 Series II GC, cabopack packed column, 3m), with an oven temperature of 120 ºC, equipped with integrator (Hewlett Packard 3396 Series II Integrator) and automatic injector (Hewlett Packard 6890 Series Injector) at 106 ºC, and FID detector at 190 ºC. The carrier gas used was nitrogen, with no heating ramp. The internal standard used was 2-methylbutyric acid. In each tube for chromatograph reading, 100 µL of the internal standard, 800 µL of the sample, and 200 µL of formic acid were added. A blend of volatile fatty acids with known concentrations was used as an external standard for integrator calibration (Campos, et al., 2004).

All results were submitted to analysis of variance using the Statistical Analyses System (SAS Institute, 1999). Data were analyzed using a completely randomized design within the following general model: $Y_{ij} = \mu + T_i + e_{ij}$. Where: Y_{ij} = the dependent variable; μ = overall average; T_i = the fixed effect of treatment (i= Baby Beef FT® or Factor LM+®); and e_{ij} = the random residual error. Significant differences were set at $P \leq 0.05$.

3. Results and Discussion

Differences were observed between treatments for the final body (P=0.03). This effect is due to significant differences observed for average daily gain (ADG). Animals fed the diet containing the Factor LM+® showed greater ADG (1.61 kg/day) than those fed monensin and virginiamycin (1.44 kg/day) throughout the experimental period (98 days). When data were analyzed by period, differences between treatments were observed only in the fourth period (P<0.01). However, a more homogeneous weight gain was observed in the treatment containing Factor LM+® (Table 3).

Table 3 - Mean and standard deviation of the initial and final body weight and the average daily gain (kg) of finisher animals fed a whole shelled corn-based diet with Factor LM+® replacing monensin and virginiamycin.

Item	**Diet**				
	Baby Beef FT®	**Standard deviation**	**Factor LM+®**	**Standard deviation**	**P-value**
Initial body weight	244.5	±18.5	269.8	± 15.8	0.12
Final body weight	384.0	±15.7	430.2	±13.2	0.03
ADG (0 – 21 days)	1.45	± 0.12	1.68	± 0.06	0.10
ADG (22 – 42 days)	1.30	± 0.29	1.31	± 0.19	0.98
ADG (43 – 56 days)	1.50	± 0.55	1.68	± 0.51	0.31
ADG (57 – 70 days)	1.42	± 0.36	1.86	± 0.40	<0.01
ADG (71 – 84 days)	1.60	± 0.12	1.61	± 0.08	0.87
ADG (85 – 98 days)	1.47	± 0.12	1.63	± 0.08	0.26
ADG (0 – 98 days)	1.42	± 0.13	1.64	± 0.14	<0.01

Source: Authors.

The results observed in the present study for ADG differ from those of Cruz et al. (2014), where a mix of essential oils (3.5 and 7.0 g/animal/day) did not alter ADG of entire crossbred animals (Nelore × Angus) compared to the control. However, the ADG observed by this author in treatments containing essential oils is similar to that of the present study in the treatment containing essential oils (1.64 *vs.* 1.64 kg/day).

Carvalho et al. (2021), observed greater ADG in feedlot finisher cattle fed essential oils (9 g/day of a blend of molasses, mannanoligosaccharides, xylanase, garlicin extracted from garlic, and cinnamaldehyde extracted from cinnamon) compared to the control diet (1.36 vs. 1.14 kg/day). Similarly, Organhi et al. (2017), reported that clove and cinnamon oils (offered separately) increased ADG when compared to the control treatment. However, no treatment effect was observed using two different experimental doses (3.5 and 7.0 g) of each essential oil used separately.

According to Geraci et al. (2012), natural feed additives have the potential to modulate ruminal fermentation and improve animal performance. In addition, as natural products, feeding essential oils to cattle does not lead to the problems involved with antibiotics and growth promoter's supplementation.

The inclusion of the Factor LM+® did not affect (P>0.05) the DMI, expressed as a percentage of BW (% BW). The average DMI observed in animals fed Factor LM+® was 2.3% BW while those fed control treatment averaged 2.31% (Table 4).

Table 4 - Mean and standard deviation of dry matter intake (% BW), feed-to-gain ratio, and fecal pH of finisher animals fed a whole shelled corn-based diet with Factor LM+® replacing monensin and virginiamycin.

Item	**Diet**				
	Baby Beef FT®	**Standard deviation**	**Factor LM+®**	**Standard deviation**	**P-value**
DMI, % BW (0 – 21 days)	2.01	± 0.12	2.04	± 0.14	0.87
DMI, % BW (22 – 42 days)	2.00	± 0.09	2.03	± 0.11	0.68
DMI, % BW (23 – 56 days)	1.99	± 0.14	2.03	± 0.09	0.59
DMI, % BW (57 – 70 days)	1.99	± 0.07	2.02	± 0.10	0.78
DMI, % BW (71 – 84 days)	1.98	± 0.21	2.02	± 0.15	0.72
DMI, % BW (85 – 98 days)	2.00	± 0.11	2.01	± 0.13	0.52
DMI, % BW (0 – 98 days)	2.00	± 0.12	2.02	± 0.08	0.89
Feed-to-gain ratio	3.6	± 0.54	3.7	± 0.42	0.92
Fecal pH	6.52	± 0.46	6.87	± 0.31	<0.01

Source: Authors.

According to Allen et al. (2009), animals fed whole shelled corn-based diets may have lower DMI than those fed a conventional diet (forage and concentrate) due to the high energy concentration in this type of diet, where the TDN values may exceed 85%. A possible explanation may be found in the greater use of the diet and consequent meeting of nutritional requirements. In this case, a greater flow of volatile fatty acids (VFA) would be provided, especially propionic acid, which increases the liver synthesis of ATP, causing inhibition of DMI via the satiety center. As in the present study, Carvalho et al. (2016), observed a DMI of 2.09% BW in finisher Angus fed a whole shelled corn-based diet.

The DMI (%BW) we observed is within the reference range (2.0% and 2.5% BW) for this animal category (Fugita, et al., 2012). Within this range, DMI is controlled by chemostatic effects; that is, DMI is inhibited by the high dietary energy and not by physical factors associated with dietary NDF concentration (Mertens, 1994).

A small oscillation between the evaluated periods was observed when analyzing the DMI (%BW) throughout the experimental period. That animals weighed 400 kg of BW (Table 3) at the end of the study suggests they were not at maturity, a point defined as when animals stop gaining muscle tissue (or gains it in a small magnitude) and increase fat deposition. According to Br-Corte 2016 (Valadares Filho, et al., 2016), dairy-crossbred male animals weigh about 616 kg of BW at maturity. At the beginning of the fat deposition, DMI (%BW) is reduced mainly due to a greater leptin secretion produced by the adipose tissue. Thus, we hypothesized that animals in our study were able to maintain high levels of DMI (%BW) throughout the experimental period, regardless of the treatment.

Although essential oils have been reported (Benchaar, et al., 2008) to reduce DMI due to intrinsic characteristics, such as taste and smell, the similar DMI (%BW) we observed suggests that the experimental dose did not interfere with the DMI. These results differ from those observed by Cardozo et al. (2006) concerning the daily dose of oils supplied to animals. These authors fed animals 180 mg/day of cinnamaldehyde oil and 90 mg/day of eugenol oil and observed a significant reduction in the DMI.

Coneglian et al. (2019), also observed no difference in DMI in Nellore animals fed high-grain diets and supplemented with levels (1, 2, 4, and 8 g/day) of essential oils of *Ricinus communis* L. (ricinoleic acid) and *Anacardium occidentale* oil (anacardic acid, cardol, and cardanol).

Thus, the accurate dose of essential oils is an important factor to be considered for positive results since low dosages can be beneficial to stimulate DMI, while higher dosages can reduce it.

Two distinct factors can partially explain the low feed conversion values. One would be the physiological stage of animals, providing a high muscle deposition that can be seen via the ADG. Indeed, muscle synthesis shows greater metabolic efficiency compared to adipose tissue (Valadares Filho, et al., 2016). The other factor may be related to the high dietary energy density, which provided a DMI (%BW) below the consumption capacity of the animals, thus improving the feed conversion (Mertens, 1994). In the study of Ornaghi et al. (2017), no difference (P>0.05) was observed in feed efficiency between the control treatment and treatments containing essential oils, even though higher DMI and ADG (7.91 kg/day vs. 6.94 and 1.47 kg/day vs. 1.28, respectively) were observed.

In a literature review, Goodrich et al. (1984) reported that monensin improves the feed-to-gain ratio of feedlot cattle by up to 7.5%. According to the authors, this enhancement is due to decreased ruminal ammonia and methane gas production. However, the feed-to-gain ratio in the treatment containing virginiamycin and monensin was similar (P>0.05) to that observed in Factor LM+® (3.6 vs. 3.7, respectively).

No significant differences between the experimental groups were observed in fecal pH (P>0.05). Maruta & Ortolani (2002) reported that fecal pH can be used as an alternative in ruminal lactic acidosis clinical diagnosis. The higher the total lactic acid in the fecal concentration, the lower the fecal pH.

Feces with lower pH (< pH 6.0) had greater starch content. Even though the animals of both experimental groups were fed a whole shelled corn-based diet (with no forage), the fecal pH values we observed are corroborated with those reported as references in the literature. Therefore, corn starch was likely either degraded in the rumen or digested and absorbed in the small intestine. Thus, little starch escaped to the gut colonizing bacteria, which possess a high capacity for lactic acid synthesis and reduce fecal pH (Ireland-Perry & Stallings, 1993).

The greater fecal pH we observed suggests a possible change in the digestion site, passing from the rumen to the posterior gastrointestinal tract. However, there is disagreement among researchers about the most efficient starch digestion site. Briefly, during ruminal fermentation, there are losses of heat and methane (Owens & Zinn, 2005), while digestion in the duodenum and jejunum may not be fully efficient due to the high digesta passage rate, enzyme adaptation to digest starch, and glucose absorption and use by the portal vein drained-viscera. Thus, a lower acid lactic production would occur in the large intestine, contributing to a greater fecal pH (Nocek & Tamminga, 1991; Channon, et al., 2004).

Animals fed Factor LM+® showed greater (P<0.01) acetic acid concentration in rumen fluid than those fed Baby Beef FT®. However, propionic and butyric acid concentrations in rumen fluid were not affected (P>0.05) by treatments (Table 5).

Table 5 - Mean and standard deviation of volatile fatty acids concentration (acetate, propionate, butyrate, and total VFA) of finisher animals fed a whole shelled corn-based diet with Factor LM+® replacing monensin and virginiamycin.

Item	Diet				
	Baby Beef FT®	**Standard deviation**	**Factor LM+®**	**Standard deviation**	**P-value**
Acetic acid (mM/mL)	3031	93.50	3515	97.19	<0.01
Propionic acid (mM/mL)	2606	296.3	2324	301.3	0.51
Butyric acid (mM/mL)	686.6	79.45	928.6	106.3	0.09
Total VFA (mM/mL)	6324	923.9	6768	788.0	0.32

Source: Authors.

The main final products of ruminal fermentation are VFA, carbon dioxide, methane, ammonia, and microbial cells. VFA are the final products of carbohydrate fermentation, and acetate may comprise up to 75% of the total VFA when ruminants are fed forage-based diets (Leng, 1970). In the present study, the acetate concentration was 47.9% and 51.9% of the total VFA in Baby Beef FT® and Factor LM+® treatments, respectively. This relatively low acetate concentration is due to consuming a diet lacking forage. Regarding propionate, the concentrations were 41.2% and 34.3% in Baby Beef FT® and Factor LM+®, respectively.

Hristov et al. (2001), and Guan et al. (2006), reported that even without an effect on the total VFA production, ionophores can alter the acetate-to-propionate ratio. This effect was observed in the present study, where the treatment with Baby Beef FT® showed an acetate-to-propionate ratio of 1.16 to 1, while the Factor LM+® showed a ratio of 1.51 to 1. A possible explanation for this can be found in the inhibition effect of ionophores on the growth of acetate-producing bacteria such as *Butyrivibrio fibrisolvens*, *Fibrobacter succinogene*s, *Ruminococcus albus*.

Dehority (2003), reported that in high-grain diets, acetate concentration is lowered while propionate concentration is increased, resulting from increased starch-degrading bacteria over the fiber-degrading bacteria population. In the present study, both dietary treatments had more than 60% DM favoring the proliferation of amylolytic bacteria that produce propionate as the final product of their metabolism.

In addition, it is well established that propionate is highly gluconeogenic and the most efficient VFA in energy metabolism. Propionate synthesis may be favored in diets containing monensin; however, our results suggest that the monensin treatment was not superior to Factor LM+® (containing essential oils) for propionate synthesis.

Bergman (1990), reported that only 30% of the ruminal acetate is metabolized by the gastrointestinal tract wall, and most are used as a source of energy in peripheral tissues. Propionate and butyrate are the most metabolized VFA (50% and 90%, respectively); thus, the greater ruminal acetate concentration in Factor LM+® may have been responsible for the greater ADG we observed in animals from this treatment as a result of a greater energy supply to peripheral tissues.

Animals fed the Factor LM+® showed greater ruminal pH (P<0.01) at 06:00 h, 14:00 h, and over a 24-h period (overall pH). Differences were not observed (P>0.05) between treatments in ruminal pH only at 22:00 h (Table 6).

Table 6 - Mean and standard deviation of ruminal pH over time of finisher animals fed a whole shelled corn-based diet with Factor LM+® replacing monensin and virginiamycin.

	Diet				
	Baby Beef FT®	**Standard deviation**	**Factor LM+®**	**Standard deviation**	**P-value**
pH – 06:00 hours	5.38	0.09	5.96	0.11	<0.01
pH – 14:00 hours	5.44	0.11	6.13	0.11	<0.01
pH – 22:00 hours	5.66	0.15	5.80	0.11	0.20
pH – overall	5.46	0.06	5.96	0.07	<0.01

Source: Authors.

That animals fed Baby Beef FT® treatment showed lower pH may be related to the greater propionate production (although no difference between treatments was observed) and lower acetate production in the rumen. Lactic acid is correlated with propionate production and is formed via two known pathways. The first involves the formation of oxaloacetate and succinate, and the second requires the conversion of pyruvate to lactate and acrylate, subsequently reducing ruminal pH. Beauchemin et al. (2001), reported that subclinical acidosis is set under ruminal pH below 5.8 for more than 12 hours.

The ruminal pH of 6.2 is just as important as 5.8. Ørskov (1982) reported that lower cellulolytic bacteria activity and lower fiber degradation begin when pH values remain around 6.2. In addition, according to Russell & Wilson (1996), a pH of 6.2 can reduce the efficiency of microbial protein synthesis. It is important to highlight that in both treatments of the present study, the pH remained below 6.2 at all times evaluated.

Furthermore, according to Owens et al. (1998), rumen microorganisms show a rapid adaptive response to high-grain diets rich in highly fermentable carbohydrates by increasing acid production, which reduces ruminal pH and the normal motility of the rumen. There are no reports of the direct action of ruminal pH on DMI. However, a greater proportion of VFA can be found protonated at low rumen pH, which increases their absorption through the rumen wall. Chemoreceptors in the rumen-reticulum wall monitor VFA concentration and ruminal pH, depressing TGI motility. High-grain diets that lead to low ruminal pH are more fluid; they hold a lower tension over the muscular layer of the rumen-reticulum, reducing ruminal motility. However, no difference was observed between the treatments for DMI, even with the significant differences in ruminal pH throughout the day we observed.

The frequent use of antibiotics (virginiamycin) and growth promoters (ionophores) in animal feeding is a public health concern (Benchaar, et al., 2008). The restrictions imposed on the use of antibiotics in animal feed are based on concerns about the development of microorganism resistance due to the inappropriate use of ionophores, compromising the therapeutic action of antibiotics in humans (Russell & Houlihan, 2003).

Ionophores are fed to ruminants to modulate ruminal fermentation, improve beneficial processes (gram-negative bacteria selection), and reduce or exclude inefficient processes (methane gas and carbon dioxide production). Thus, essential oils have been considered promising substances to improve ruminal fermentation due to their antimicrobial effect, similar to some antibiotics and growth promoters.

4. Conclusion

It was concluded that replacing monensin and virginiamycin with essential oils and short-chain fatty acids in beef cattle fed whole shelled corn-based diets was effective for performance without impairing ruminal fermentation, which could compromise animal health. These essential oils may be a natural and safe alternative to feed animals with greater metabolic challenges.

The authors suggest that further research should continue to be carried out to replace chemical additives that are used in animal nutrition without loss of animal performance.

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